How to limit significantly direct and indirect emissions of GHGs in commercial refrigeration?

International Symposium on Near-Term Solutions for Climate Change Mitigation in California

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MINES PARIS ARMINES
CENTRE ÉNERGETIQUE ET PROCEDES

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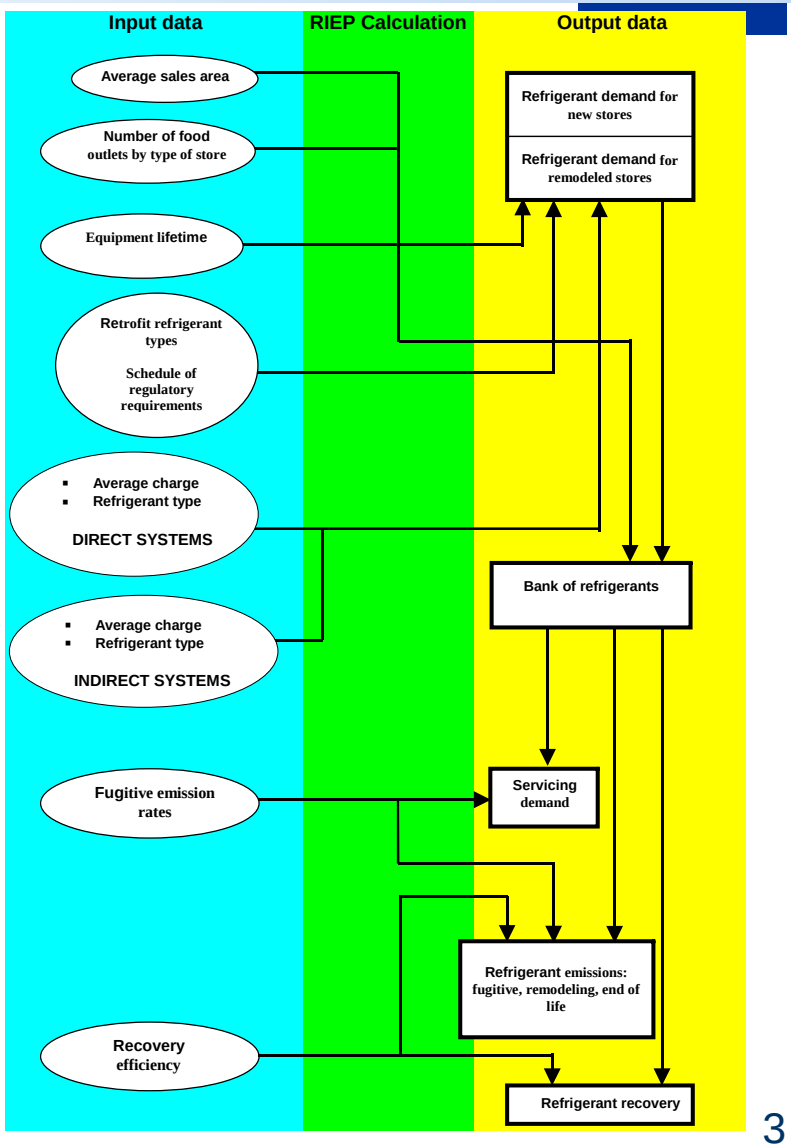
- Global banks and emissions of refrigerants in the commercial sector
- Evaluation of energy consumption of commercial refrigeration systems
- Main technical evolutions for limitation of refrigerant emissions
- Main technical evolutions for energy efficiency improvements
- 2007 – 2012: the end of HCFCs

Refrigerant banks and emissions in the commercial sector

- Inventories of refrigerants based on IPCC Tier 2 method.
- The method requires the inventories of commercial outlets.



Refrigerant banks and emissions in the commercial sector

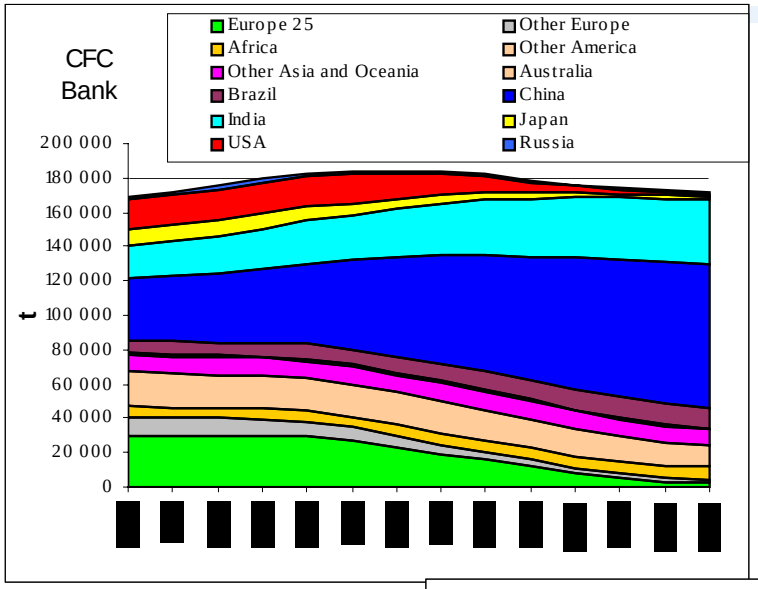
Note: hypermarket = large supermarket ($S > 2500\ m^2$)

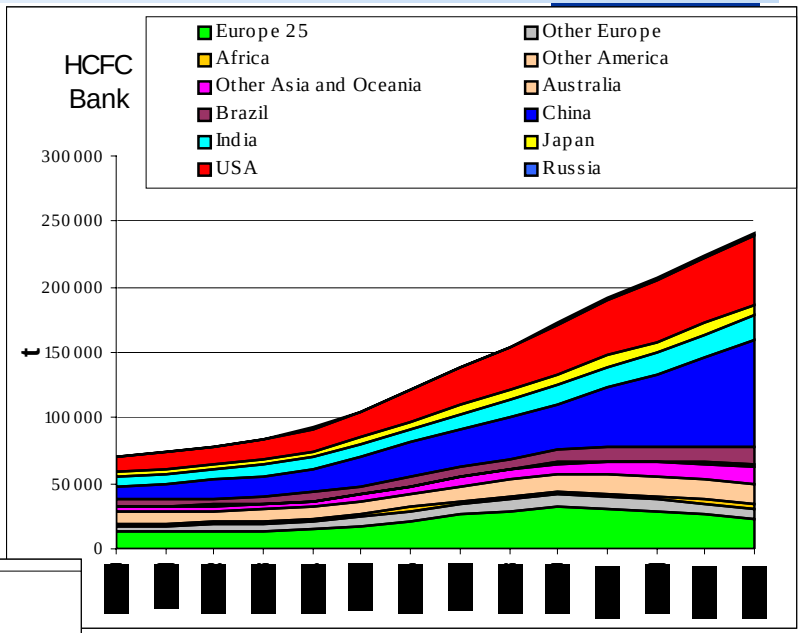
2003	Supermarkets	Hypermarkets
USA	33 841	3 568
Brazil	15 100	232
Australia	1 822	2
China	288 000	311
Japan	15 181	1 457
Russia	1 118	31
India	500	0
Europe 25	58 752	6 236
Other Europe	10 503	429
Other America	7 344	773
Other Asia and Oceania	26 599	1 791
Africa	3 274	95
TOTAL	**462 034**	**14 925**

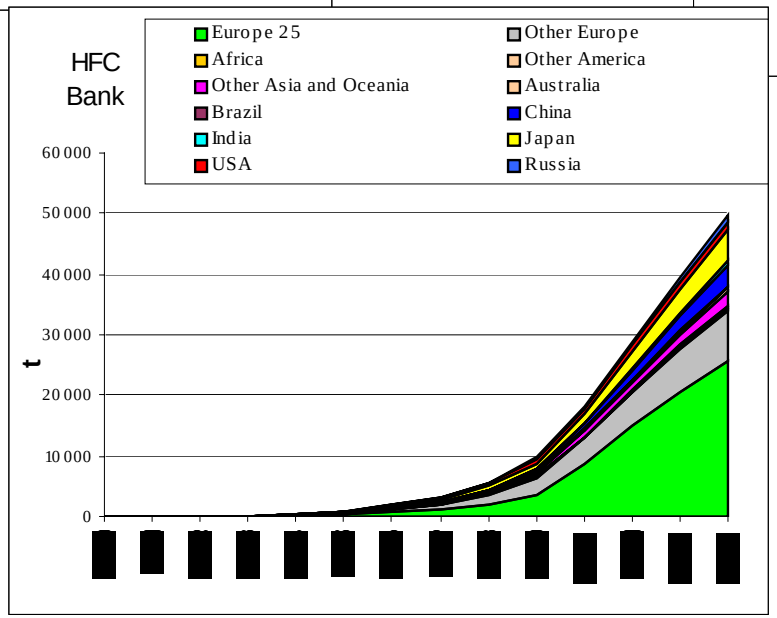
- Average refrigerant charge per m^2 of sales area in 2003.

Supermarkets	Hypermarkets	Indirect systems
0.29	0.27	0.12

Refrigerant banks in the commercial sector

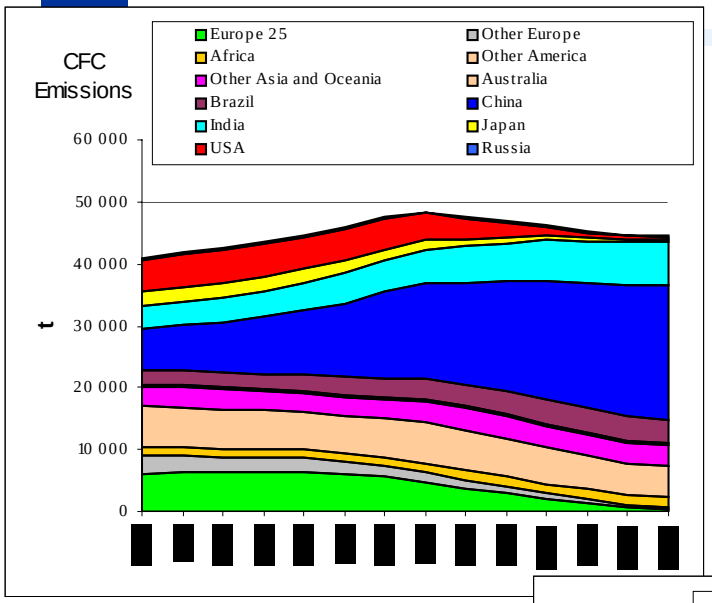


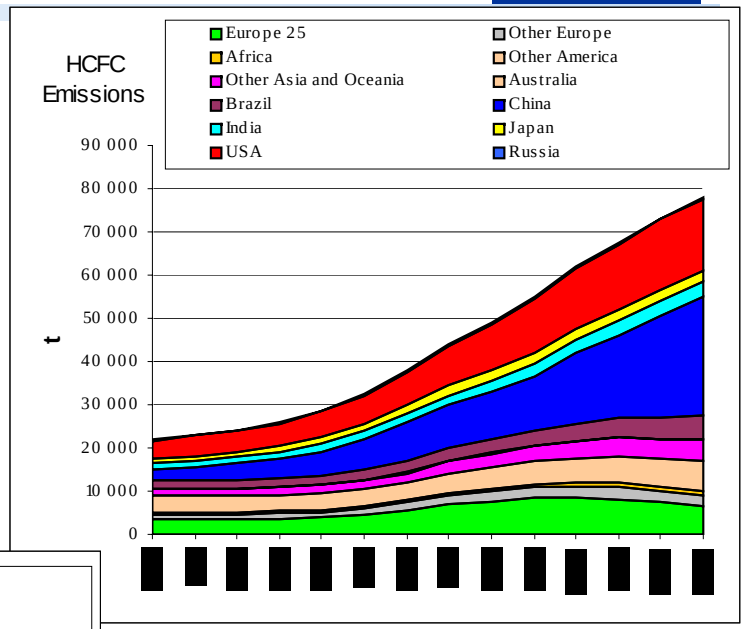


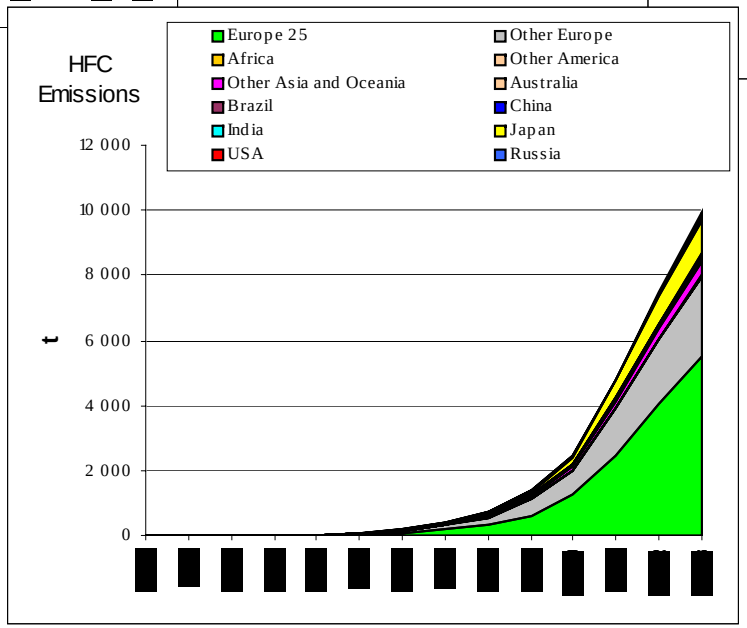


The HCFC bank is the dominant one with more than 250,000 mt in 2003.

Refrigerant emissions in the commercial sector

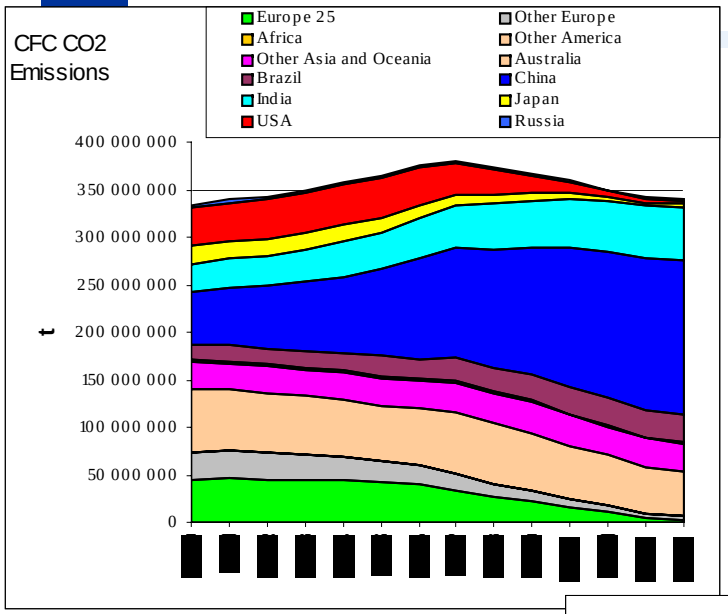


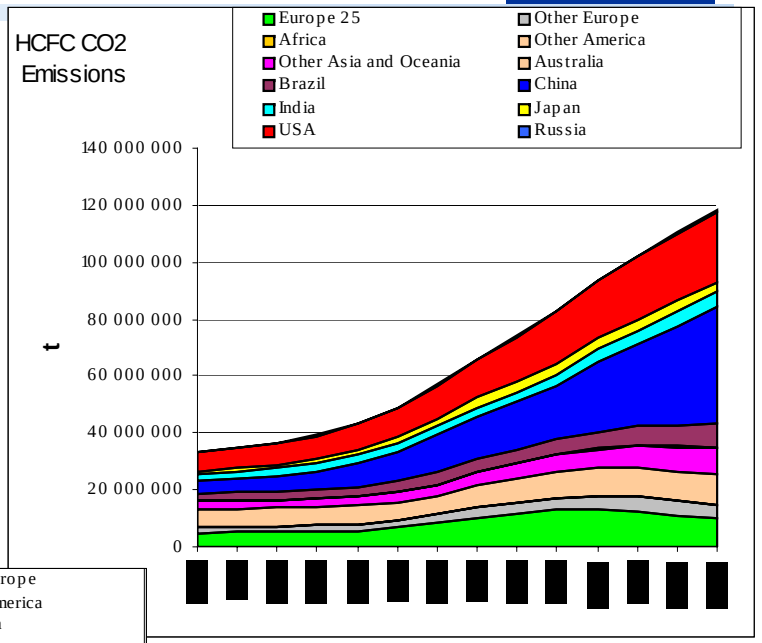


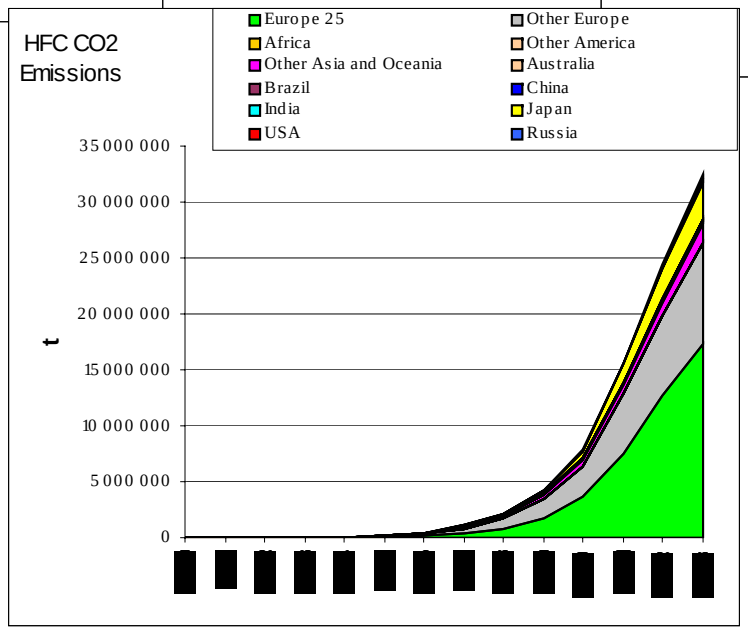


Annual refrigerant emissions are about 135,000 mt, nearly 60% being HCFCs.

Refrigerant emissions in CO_2 eq. in the commercial sector



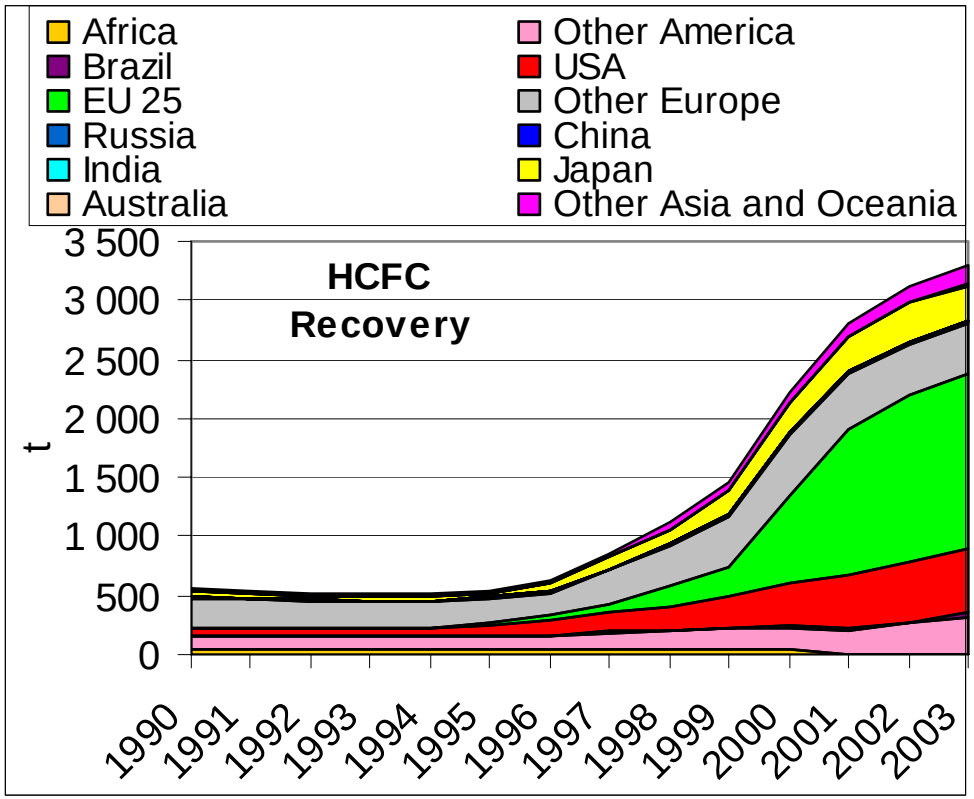




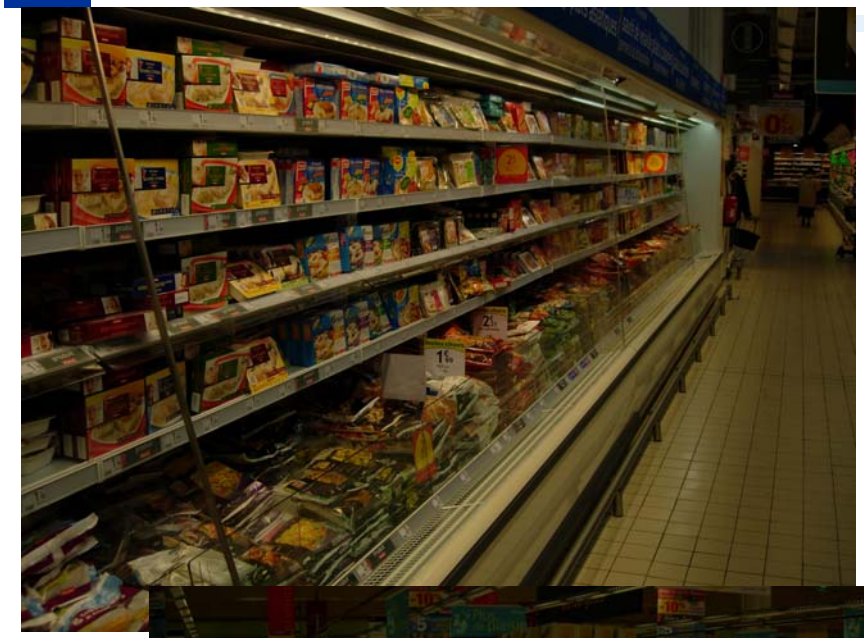
Expressed in CO_2 eq. it is about 550 million of tonnes eq. CO_2 dominated by the CFC eq. CO_2 emissions.

Refrigerant recovery in the commercial sector

- Current refrigerant recovery represents less than 10% of the potential recoverable refrigerants



Evaluation of energy consumption of commercial refrigeration systems



Evaluation of energy consumption of commercial refrigeration systems

Recent European supermakets		MT large supermarkets	LT large supermarkets	MT Medium supermarkets	LT Medium supermarkets
Average surface	m2	6000	6000	1200	1200
Average installed power per supermarket	kW	500	80	120	30
Average charge rate of installations	kW/kW	60%	80%	60%	80%
Useful refrigerating capacity	kW	300	64	72	24
Cold rooms	%	25%	15%	25%	15%
Refrigerating capacity for display cases	kW	225	54.4	54	20.4
Number of hours open to customers per day	hours	12	12	10	10
Number of open days per week	days	6	6	6	6
Annual operating time (h)	hour	8760	8760	8760	8760
COP		2,5	1,6	2,5	1,6
Annual energy consumption (kWh)		**788,400**	**297,840**	**189,216**	**111,690**
Total (GWh)		**1.08**		**0.3**	

- Assuming that 1/3 of the sales area is dedicated to food in large supermarkets, the refrigerating energy is of 540 kWh/m^2.yr, and for medium size supermarkets of 250 kWh/m^2.yr.

TEWI Evaluation of commercial refrigeration systems

Recent European supermakets		Large supermarkets	Medium supermarkets
Average surface	m2	6000	1200
Average refrigerant charge	kg	1600	350
Average emission rate	%	30%	20%
Annual emissions	kg	480	70
CO2 eq. Emissions (R-22)	tonnes	720	105
CO2 eq. Emissions (R-404A)	tonnes	1565	228
Annual energy consumption for refrigeration	GWh	1.4	0.384
Average CO2 content of US kWh	gCO2/kWh	600	600
CO2 emissons due to refrigeration energy consumption	CO2 tonnes	840	230
Annual TEWI emissions	CO2 tonnes	1560	458
Ratio direct emissions / total emissions	%	46	50

- The refrigerant emissions measured in CO_2 eq. are :
  - equal to CO_2 emissions due to energy consumption when R-22 is the refrigerant
  - but 2 times higher when R-404A is the refrigerant in use.

Limitation of refrigerant emissions by containment policies

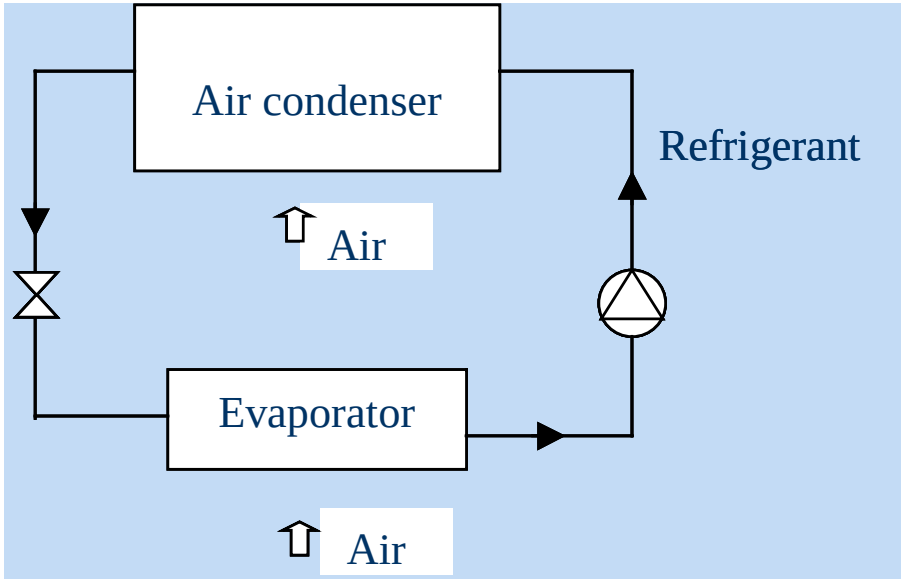
- The Containment policies established in many developed countries require:
  - annual (or more frequent) leak flow rate controls
  - efficient recovery of refrigerants at end of life of equipment
  - training of service company technicians
  - initial control of leak tightness of new system in order to guarantee a minimum initial leak flow rate.
  - annual declaration of sales of refrigerants.

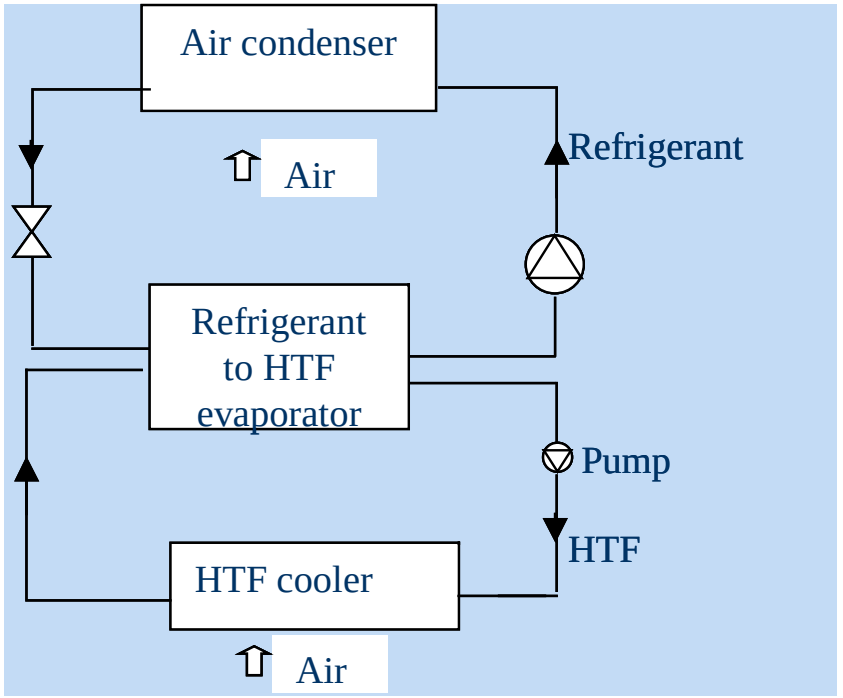
- To implement those policies it is necessary to define standards for:
  - recovery efficiency of recovery equipment
  - minimum sensitivity of leak detectors
  - method of test for leak tighness measurement and control
  - refrigerant containment standard addressing all the life cycle of refrigerating equipment.

Limitation of refrigerant emissions by system design and refrigerant choice (2)

- For commercial refrigeration, a number of new systems have been developed in the last ten years in order to limit the refrigerant charge.

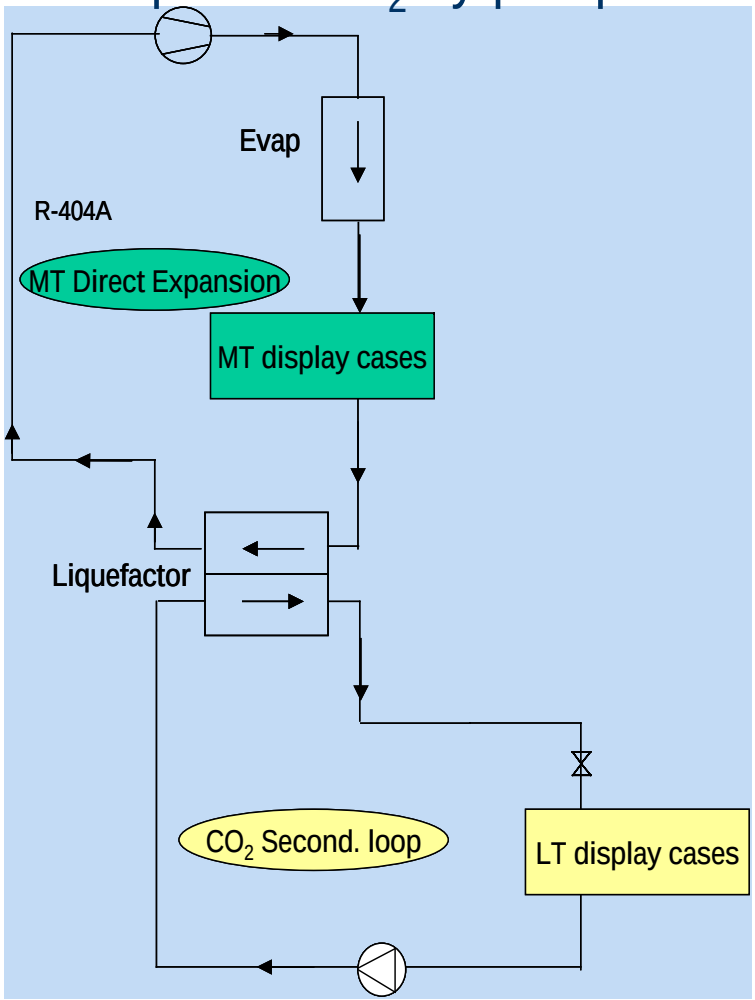
- Direct expansion system and indirect systems



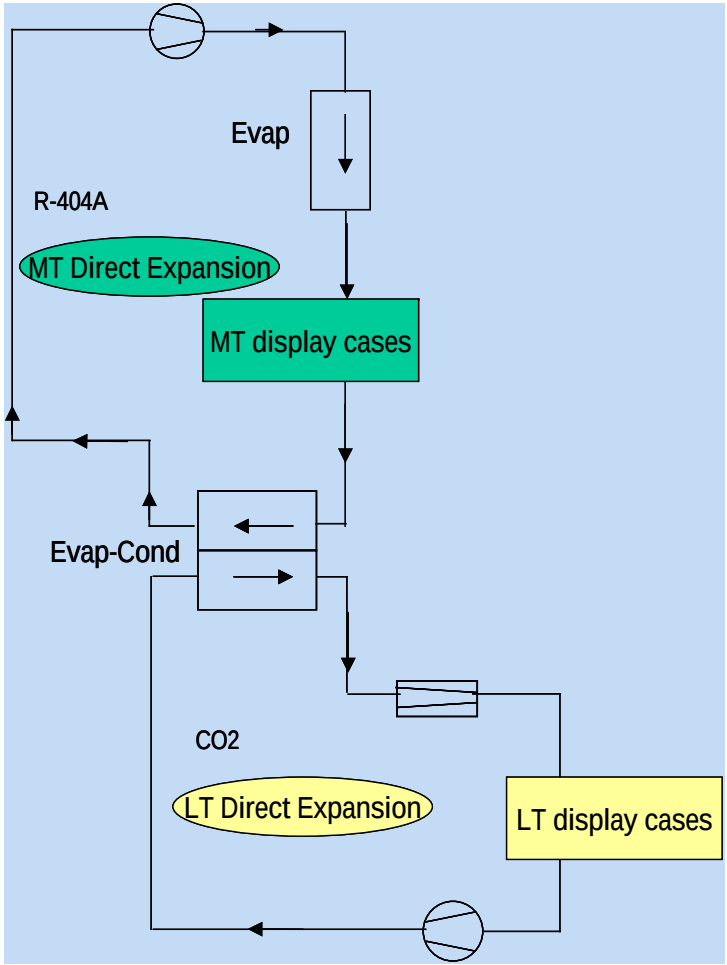


Low temperature CO_2 systems

2-phase CO_2 by pump



Cascade CO_2 / R-404A



R-404A / CO_2 cascade system (1)

R-404A / CO_2 cascade system (2)

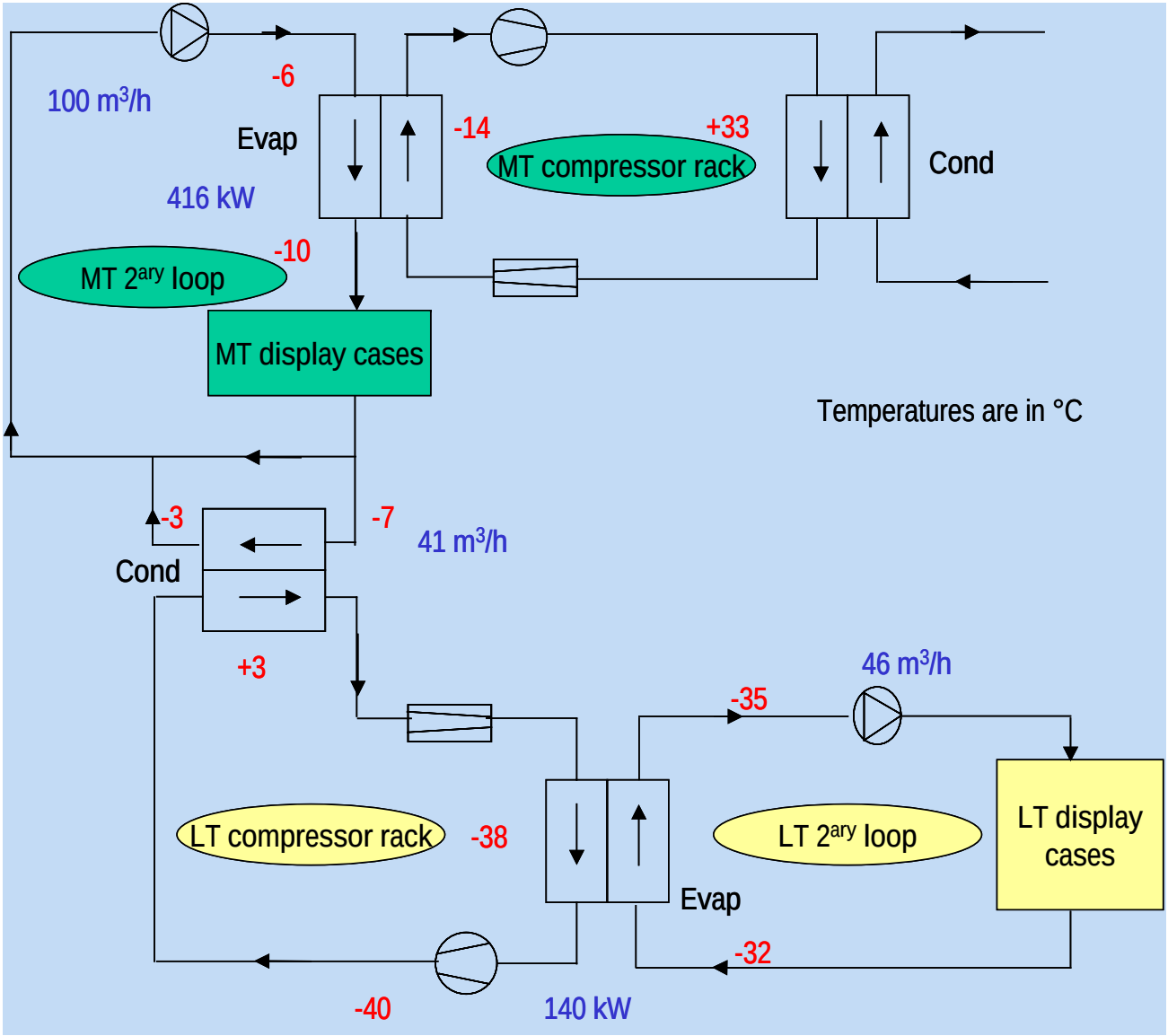
- The R-404A refrigerant charge has been reduced by 25%
- The COP of the system is higher of 10% due to compressor choice and overall design
- The cooling capacity is identical
- The initial cost is 5% higher due to the prototyping

R-404A / CO_2 secondary loop (1)

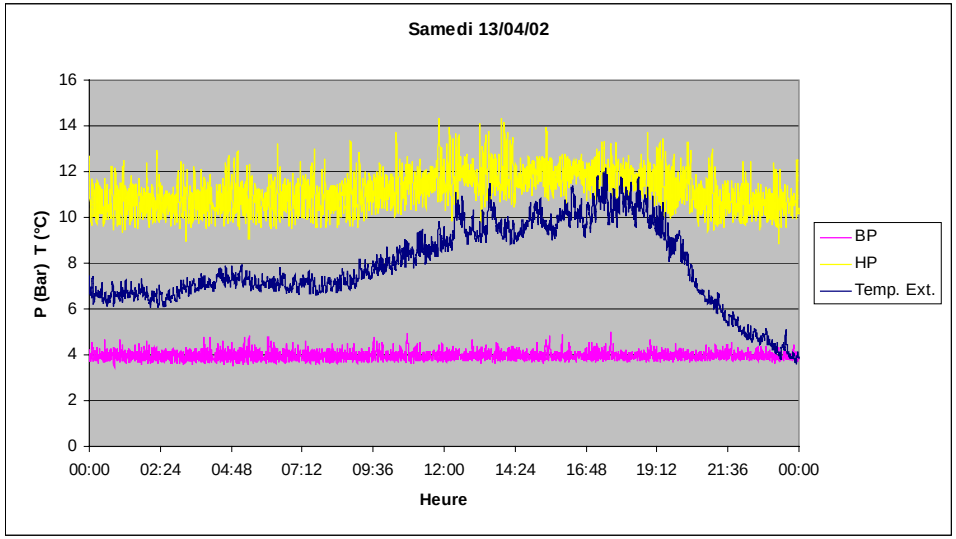
R-404A / CO_2 secondary loop (2)

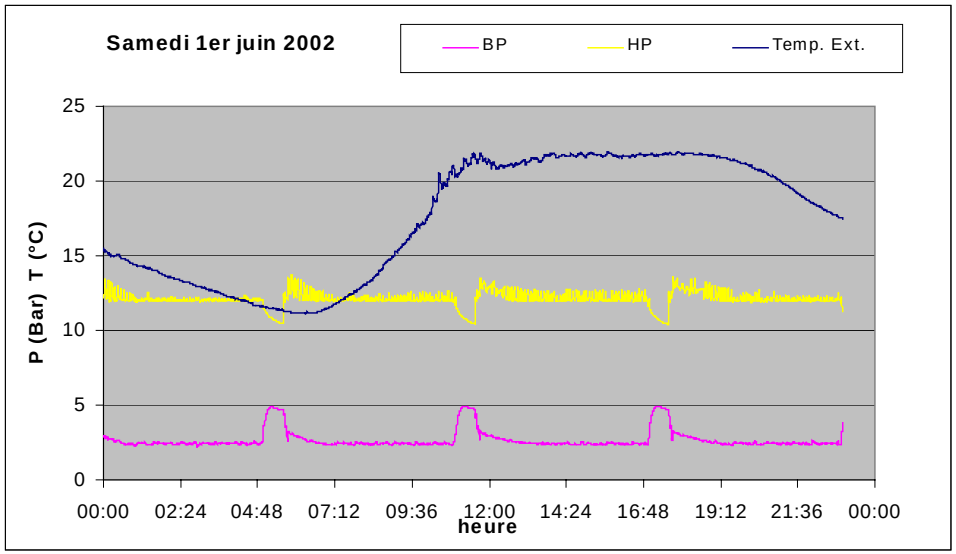
- The R-404A refrigerant charge has been reduced by 30%
- The COP of the system is slightly lower (the energy consumption of the CO_2 pump represents 2% of the compressor energy consumption)
- The cooling capacity is identical
- The initial cost is identical

Indirect system at the medium and low temperature levels



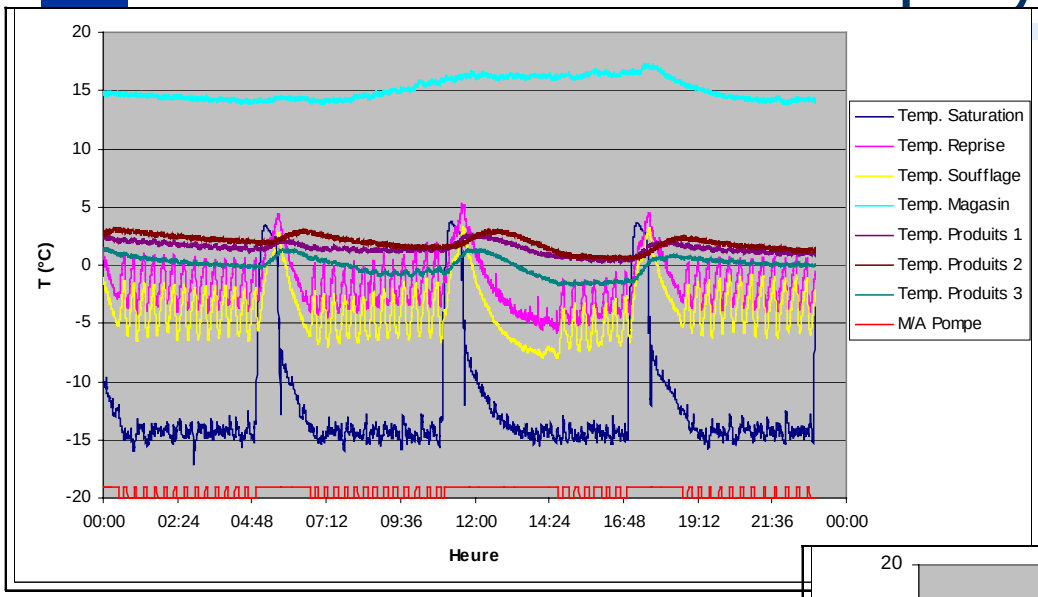
Comparison of a direct R-404A system and the indirect system





Pressure comparisons: the indirect system leads to lower variations of evaporating pressure because of the higher heat capacity of the Heat transfer fluid compared to air.

Temperature comparison of medium temp. display cases

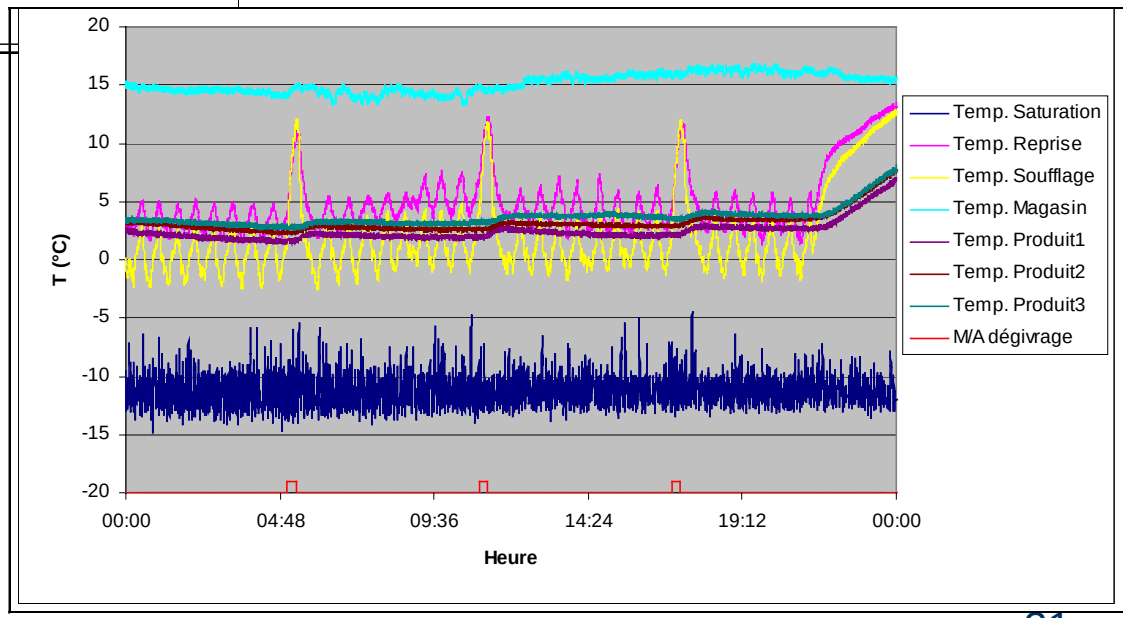


Temperatures with indirect system

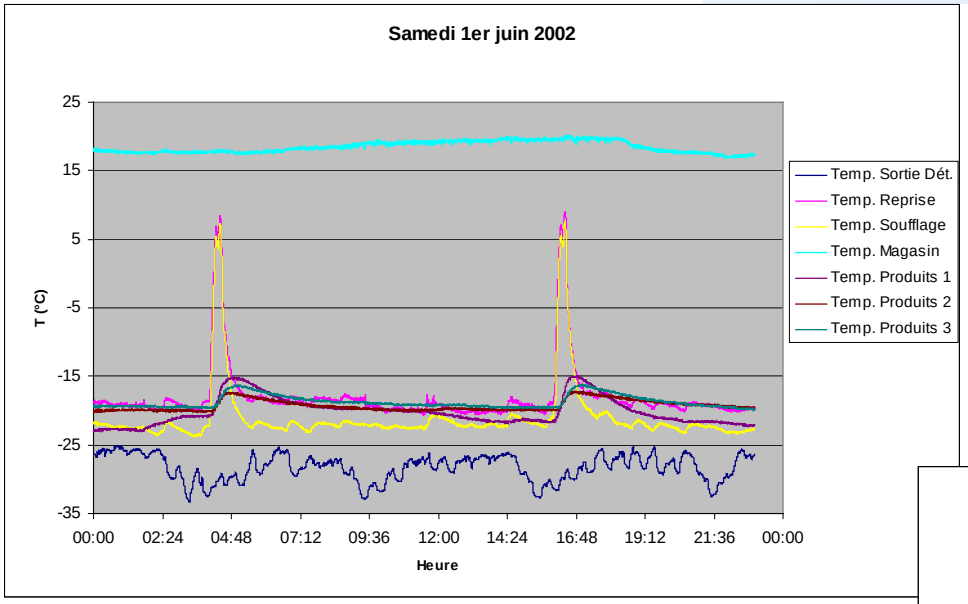
- products +2°C
- evaporation –14°C

Temperatures with direct system

- products +3.5°C
- evaporation –12.5°C

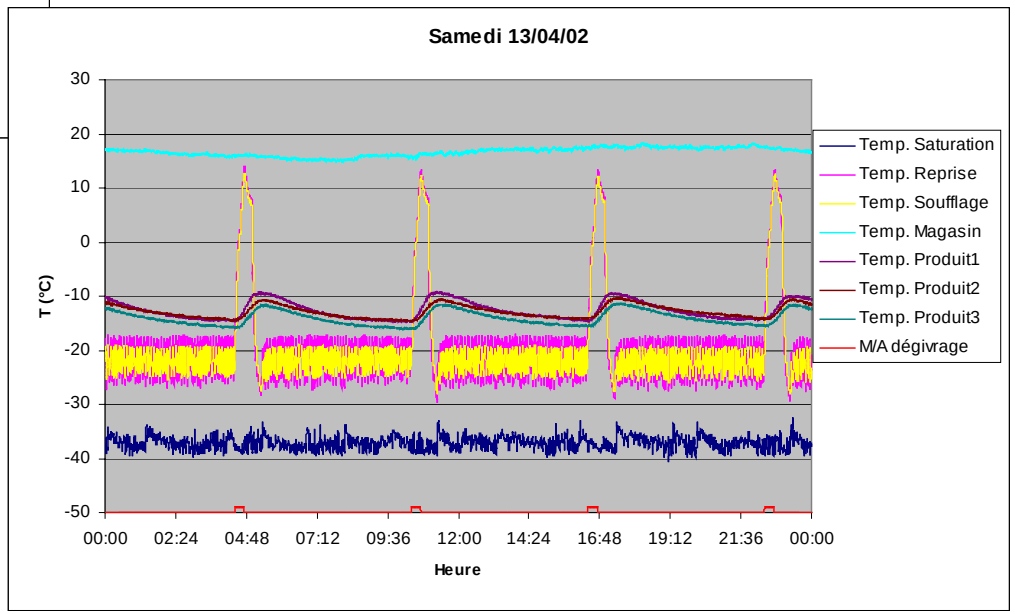


Temperature comparison of low temp. display cases



Temperatures with indirect system

- products -20°C
- evaporation –29°C
- 2 defrostings



Temperatures with direct system

- products -18°C
- evaporation –38°C
- 4 defrostings

Main lessons learnt

Medium temp. COPs
Including pumps for indirect syst.

- COP_{direct} = 2,72
- $COP_{indirect}$ = 2,65

Low temp. COPs
Including pumps for indirect syst.

- COP_{direct} = 1,12
- $COP_{indirect}$ t = 1,13

- Heat exchanger surfaces of Med Temp. Hex of indirect system are 70% larger than those of direct Hex.
- Heat exchanger coefficients are 3 times higher for indirect system Hex.
- Heat exchanger surfaces of Low Temp. Hex of indirect system are 25% larger than those of direct Hex and Heat exchange coefficients are also 3 times higher
- Compressor designs are different: higher efficiency for the indirect system compressor rack (size effect).

Main lessons learnt

- Food products are kept at the same level of temperature, but within a lower interval of temperatures for indirect systems.
- Energy consumption of HTF pumps represents about 5 to 10% of the energy consumption of the compressor racks, but is compensated by the higher level of evaporating temperature (Low temp rack) and the higher efficiency of compressors.
- The energy consumption of the new R-404A direct system is comparable to the energy consumption of the studied indirect system.
- The refrigerant charge has been lowered by a factor 4.

Main technical evolutions for energy efficiency improvements: the heating loads

- Doors and display cases
  - The opening of open display cases represents 70 to 80% of the thermal loads
  - Number of display cases without doors
  - Pattern of door openings depending on the hour, the day, the month
  - Analysis of effective opening times of display cases with doors
  - Technical and economical analysis of energy gains associated with introduction of doors on open type display cases.
- All those elements need to be addressed in order to evaluate the energy gains, which vary between 15 and 35%.

Main technical evolutions for energy efficiency improvements: the heating loads

- Night curtains and display cases
  - Analysis of the number of opening hours of the sales area
  - Automated night curtains
  - Modification of the ventilation control when night curtains are drawn
  - Modification of the defrosting control

- LED lighting, indirect lighting leads to significant lower thermal loads on the products

Main technical evolutions for energy efficiency improvements

- The compression system: a number of possible high efficiency designs
  - Cascading system
  - Deep sub-cooling for summer conditions
  - High efficiency compressors
  - Floating high pressure

- The heat exchangers
  - A better overall design including efficient defrosting
  - New fins
  - Smaller tube diameters

Main technical evolutions for energy efficiency improvements

- The control system
  - How to handle superheat?
  - How to handle defrosting?
  - Evolution or revolution?

- But
  - The designs will be on different paths when using indirect or direct systems
- And
  - Overall design of low energy consumption commercial stores is not limited to refrigeration: lighting, AC,…

The Challenge - From R-22 to the next refrigerants: How to improve the LCCP of refrigeration?

- The refrigerant bank in the commercial refrigeration sector is mainly composed of HCFC-22
- « Intermediate » blends such as R-422A or R-417A have to be evaluated in terms of easiness for the retrofit but also based on their GWP and energy efficiency.
- Recovery of R-22: how to be efficient ?
- Is R-404A a long term solution with a GWP of 3260 ?

Conclusions

- Refrigeration represents at least 50% of the energy consumption of commercial outlets
- R-22 emissions present the same CO_2 impact as energy consumption
- The CO_2 equivalent emissions of refrigerant will increase when switching the same system from R-22 to R-404A
- Limitation of refrigerant emissions as well as energy gains are possible within a number of technical options
- LCCP is the key criterion for evaluation of all technical options